Development and Operation of an Automatic Rotor Trim Control System for use during the UH-60 Individual Blade Control Wind Tunnel Test

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ABSTRACT

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Introduction

A full-scale wind tunnel test to evaluate the effects of Individual Blade Control (IBC) on the performance, vibration, noise and loads of a UH-60A rotor was recently completed in the National Full-Scale Aerodynamics Complex (NFAC) 40- by 80-Foot Wind Tunnel [1]. A key component of this wind tunnel test was an automatic rotor trim control system that allowed the rotor trim state to be set more precisely, quickly and repeatably than was possible with the rotor operator setting the trim condition manually. The trim control system was also able to maintain the desired trim condition through changes in IBC actuation both in open- and closed-loop IBC modes, and through long-period transients in wind tunnel flow. This ability of the trim control system to automatically set and maintain a steady rotor trim enabled the effects of different IBC inputs to be compared at common trim conditions and to perform these tests quickly without requiring the rotor operator to re-trim the rotor. The trim control system described in this paper was developed specifically for use during the IBC wind tunnel test.

Trim Control Description

Blade pitch control of the UH-60A rotor system was provided through three identical non-rotating swashplate actuator assemblies, each of which includes both primary and dynamic actuators. The primary actuators are high-authority / low-speed electric actuators that provide primary control of rotor blade pitch by tilting the swashplate. These actuators are controlled directly by the rotor operator through the rotor control console. The dynamic actuators are low-authority (+/- 2 degrees of blade pitch for this test) / high-speed hydraulic actuators that are used by the trim control system to provide time-varying control of the swashplate position to provide trim control functionality. Each primary/dynamic actuator pair operates in series to provide the total swashplate actuation.

Two main trim control methods were built into the rotor trim controller. The first trim method controlled the rotor lift and hub pitching and rolling moments through swashplate collective, longitudinal cyclic, and lateral cyclic pitch changes through the swashplate dynamic actuators. The rotor propulsive force was controlled through changes to the model shaft angle that were implemented manually. The trim controller calculated the shaft angle change required to obtain the desired propulsive force based on a look-up table of the propulsive force sensitivity to shaft angle

change. The second trim method controlled the rotor lift, propulsive force and hub rolling moment through the three swashplate controls. This trim method was performed with the shaft angle fixed since the rotor propulsive force was controlled directly through swashplate inputs. Both methods were effective at controlling rotor trim, but the second method was more time effective since the rotor was trimmed and re-trimmed in a matter of seconds with swashplate inputs, where the first method required manual changes in model shaft angle which took considerably more time.

The control architecture for each of the trim methods described above uses PI (proportional and integral) control in each of the three swashplate control channels. The trim control logic, including inner-loop trim control, mode switching, etc. were written in Matlab Simulink. The Simulink block diagram for the trim controller is shown in Figure 1. An initial set of control law gains were calculated using the Control Designer's Unified Interface (CONDUIT) program [2] based on a set of stability, performance and disturbance rejection specifications. The rotor dynamics model used to calculate the control law gains was obtained using the FORECAST simulation code [3]. The control system gains were tuned during initial wind tunnel testing to the final set of gains that were used during research data collection.

The Simulink block diagram was complied into an executable library that was run on the trim control hardware, that consisted of a National Instruments real-time system and an operator interface written in National Instruments Labview. A screen-shot of the operator interface developed for the trim controller is shown in Figure 2. This operator interface allowed the operator to control and monitor all aspects of trim controller, including the controller configuration, trim set point, trim method and controller operation.

Trim Control Results

Figure 3 shows some example data from the wind tunnel test that illustrates the performance of the rotor trim control system. This data was collected with the rotor in a 1 g lift condition at 150 knots and 2/rev IBC phase sweeps (IBC phase angles of 0 deg, 30 deg, 60 deg, … 330 deg in single 200 second data runs). The plot at the top shows the rotor rolling moment response during the 2/rev IBC phase sweep with the swashplate fixed (trim control system turned off). Here there are large changes in rotor rolling moment response due to IBC actuation indicating that the 2/rev IBC phase has a significant effect on the rotor trim state. The second plot shows the time history of rolling moment for another 2/rev IBC phase sweep, this performed with the trim control system active. Here the rolling moment and rotor trim condition are held constant by the trim control system during changes in IBC actuation. This enables the effect of 2/rev IBC at different phase angles on rotor performance to be evaluated at a common trim state, and shows the effectiveness of the trim controller at holding the rotor trim state constant.

Scope of the Paper

The final paper will present details of the development of the trim control system including the rotor and automatic trim system hardware and software control architectures and operator interface, calculation of initial control law gains and operational tuning of the trim system. The paper will also describe the procedures for trim control operation during the wind tunnel testing and show results evaluating the different trim control modes and performance at holding to rotor trim state constant.

References

[1] Norman, T.R., et al, "Full-Scale Wind Tunnel Test of a UH-60 Individual Blade Control System for Performance Improvement and Vibration, Loads and Noise Control," Proceedings of the American Helicopter Society 65th Annual Forum, Grapevine, TX, May 27-29, 2009.

[2] Tischler, M.B., et al, "A Multidisciplinary Flight Control Development Environment and its Application to a Helicopter," IEEE Control System Magazine, Vol. 19, No. 4, August 1999.

[3] Kim, F.D., Celi, R., and Tischler, M.B., "High Order State Space Simulation Model of Helicopter Flight Mechanics," Journal of the American Helicopter Society, Vol. 38, No. 2., October 1993.

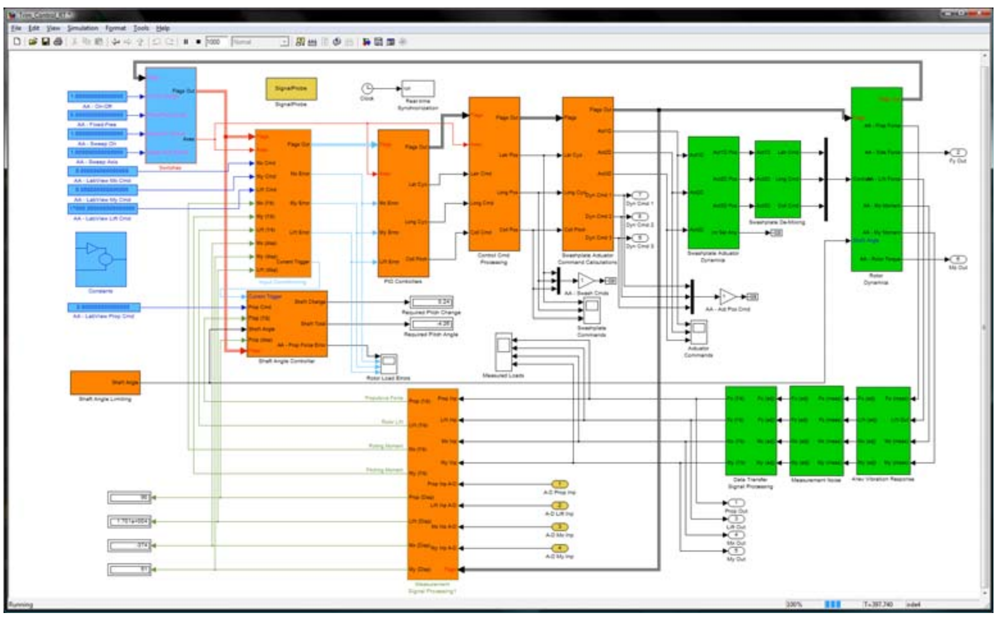

Figure 1: Block diagram of trim controller written in Matlab SimuLink.

Figure 2: Trim Controller operator interface written in National Instruments Labview.

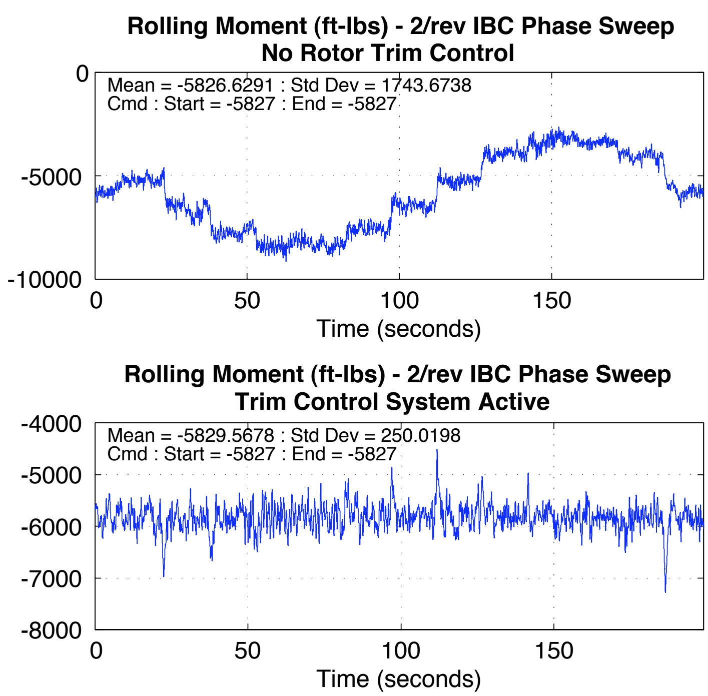

Figure 3: Time histories of hub rolling moment during 2/rev IBC phase sweeps with no trim control (top) and trim controller active (bottom).